Narrow Resonances in Effective Field Theory[1]

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Reactions involving more complex nuclei are frequently characterized by narrow resonances near threshold. One example, the $p_{3/2}$ resonance in neutron-alpha scattering. A good description of the data throughout the resonance region has been found at the expense of the resummation of two operators in addition to the unitarity cut. Such a resummation requires *two* fine-tunings, which is unnatural (in the effective theory sense) and, consequently, very hard to appear in Nature.. Here we generalize the analysis of shallow, narrow resonances in EFT. We discuss the power counting for resonances in any partial wave, and show that only *one* fine tuning is required to describe th data. We also clarify the scope of unitarization.

Our results are summarized in Fig. (1). The diamonds are "evaluated data points" from Ref. [2]. In order to have an idea of the error bars from individual experiments we also show data from Ref. [3] as the black squares. The EFT in leading (LO), subleading (NLO), and subsubleading (NNLO) orders is represented by the solid red, green, and blue lines, respectively. At LO the scattering length and effective range in the $p_{3/2}$ partial wave as well as the scattering length in the $s_{1/2}$ partial wave contribute. The data are reproduced up to neutron energies of about $E_N = 0.5$ MeV. Interestingly, the NLO result, which contains only the leading unitarity correction to the LO result and adds no new parameters, worsens the description of the data. At NNLO three more parameters enter: the shape parameter in the $p_{3/2}$ wave, the effective range in the $s_{1/2}$ wave, and the scattering length in the $p_{1/2}$ wave. The data are described up to $E_N \approx 0.8$ MeV at NNLO. As expected, the EFT describes the data qualitatively, but it fails in the immediate neighborhood of the resonance. In order to improve the description in this neighborhood, we need to resum the interaction that gives rise to the resonance width. For comparison, we show the first two orders of the resummed EFT as the black dashed (LO) and black solid (NLO) lines. The improvement around the resonance is evident. Because the scales M_{lo} and M_{hi} are not very well separated, that is, M_{lo}/M_{hi} is not very small, the region of improvement is relatively large. The resummation is useful throughout the low energy resummation.

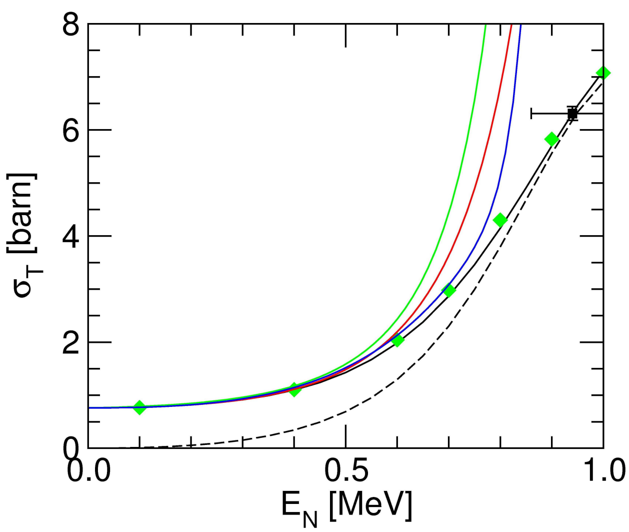

FIG. 1: The total cross section for $n\alpha$ scattering (in barns) as a function of the neutron kinetic energy in the α rest frame (in MeV). The diamonds are evaluated data from Ref. [2], and the black squares are experimental data from Ref. [3]. The solid red, green, and blue lines show the result in the EFT without resummation at LO, NLO, and NNLO, respectively. The black dashed and solid lines show the result in the EFT with resummation at LO and NLO, respectively.

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[2] *Evaluated Nuclear Data Files*, National Nuclear Data Center, Brookhaven National Laboratory (http://www.nndc.bnl.gov/).
[3] B. Haesner et al., Phys. Rev. C **28**, 995 (1983); M.E. Battat et al., Nucl. Phys. **12**, 291 (1959).